SEMINARI INTERDISCIPLINARI DI CULTURA AERONAUTICA

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I requisiti per i turbomotori di nuova generazione.

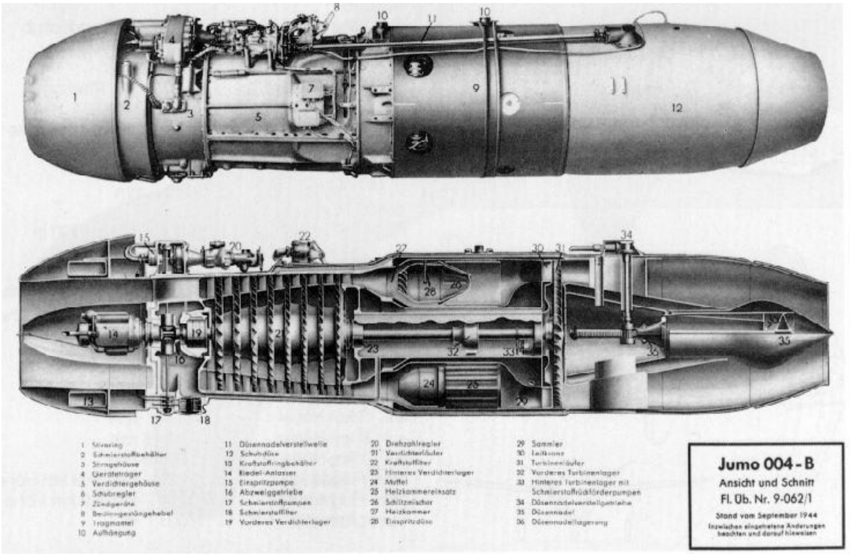
G.Mainiero

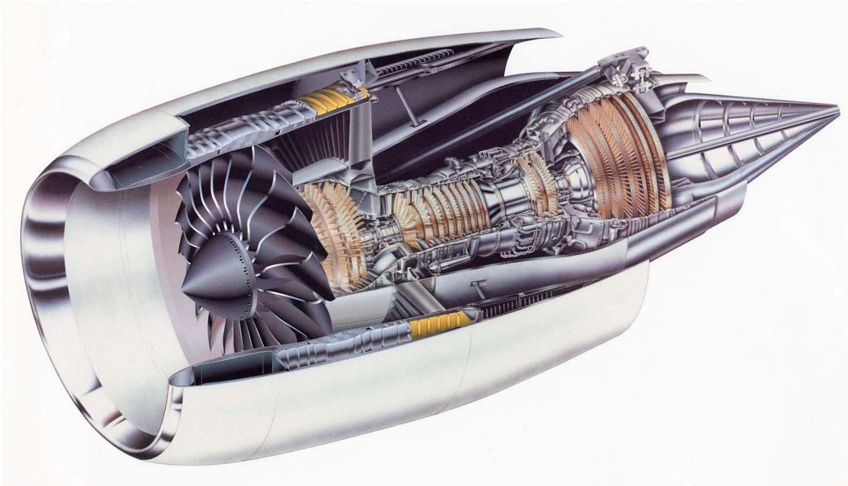
11 giugno 2016

In 70 years similar layout

Jet engine = Compressor + Combustion chamber + turbine

Junkers Jumo 004 **General Electric GE 90-115B**





Evolution trends

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- Increase propulsive efficiency
- Decrease fuel consumption
- Decrease pollution
- Decrease noise
- Increase component life

THRUST VS. PROPULSIVE EFFICIENCY

$$T = \dot{m}\left(V_e - V_0\right)$$

Conflict ↕

$$\eta_{propulsive} = \frac{2}{1 + \frac{V_e}{V_0}}$$

Important for both fighter and commercial aircraft

T/W usually more important for military aircraft (maneuverability)

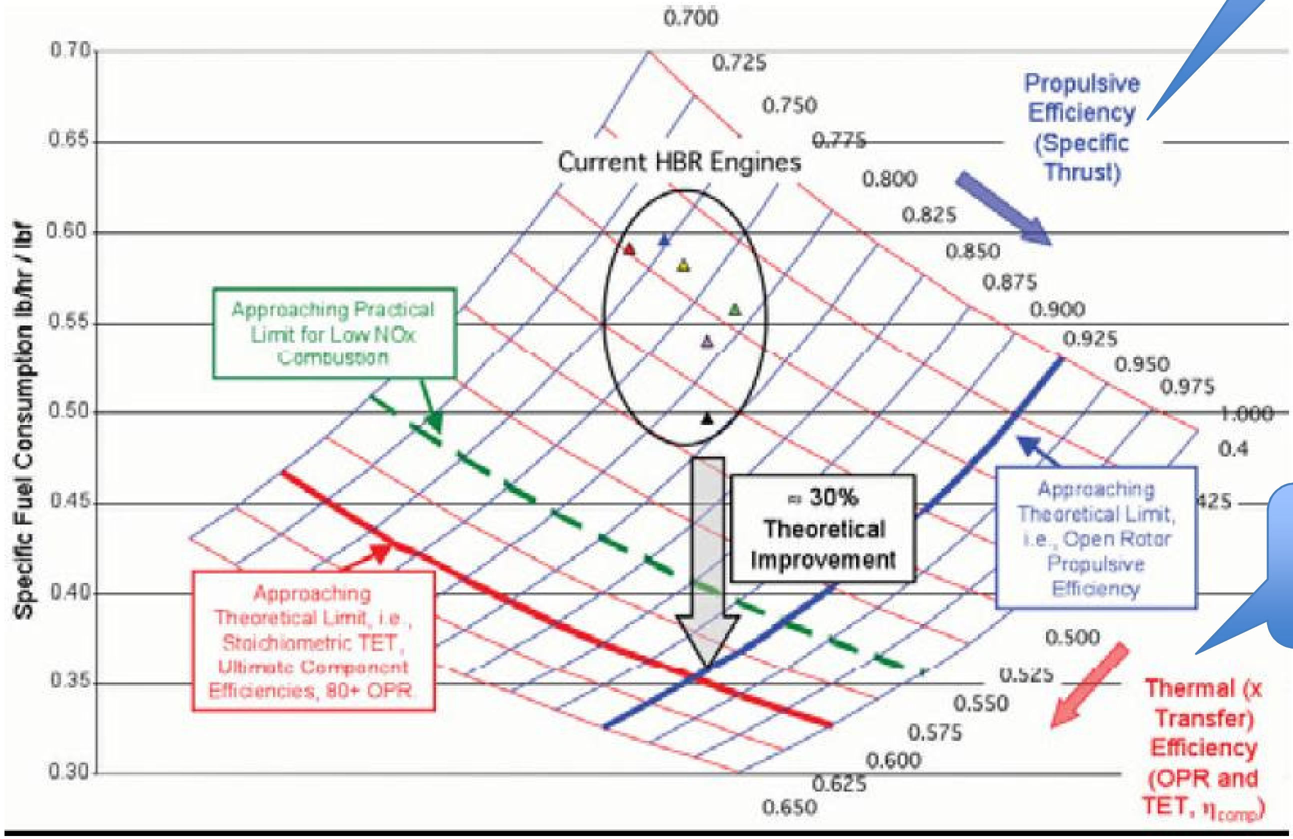
Large mass flow means high W
Fighter → ΔV

Extremely important for commercial aircraft, much less so for fighter

Efficiency critical for commercial
Low ΔV, high mass flow

Design point calculations

Increase
By pass

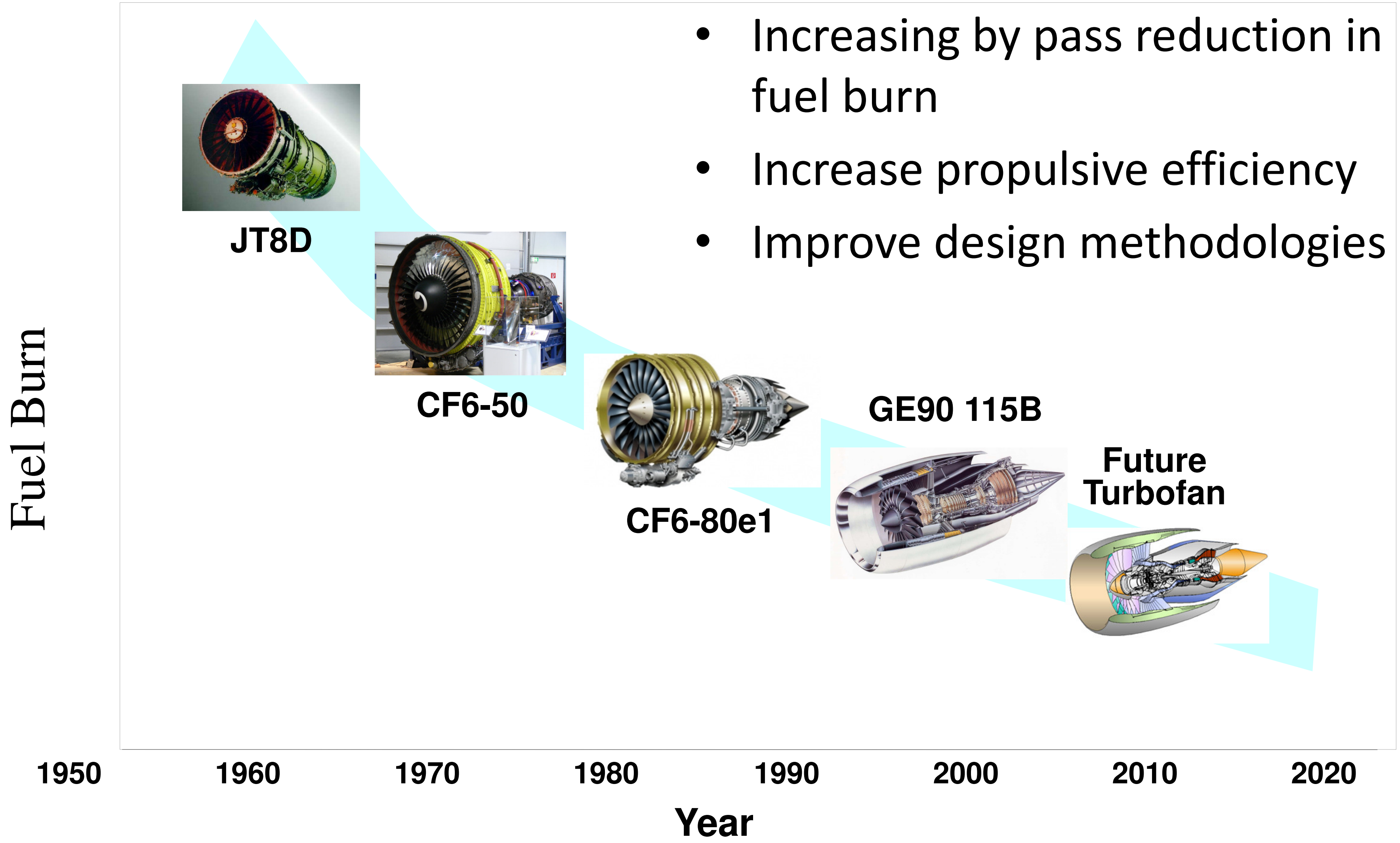


Increase
OPR and
TET

Specific thrust

Increase propulsive efficiency

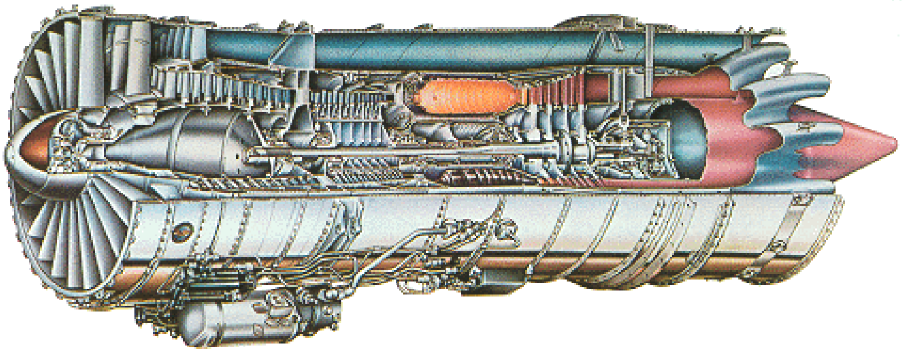
- Increasing by pass reduction in fuel burn
- Increase propulsive efficiency
- Improve design methodologies



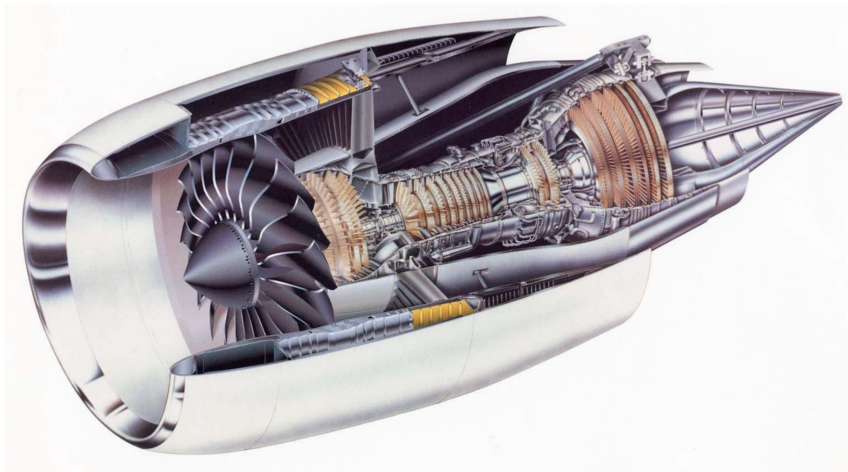
TRENDS TO BIGGER ENGINES

1958: Boeing 707, United States' first commercial jet airliner

1995: Boeing 777, FAA Certified

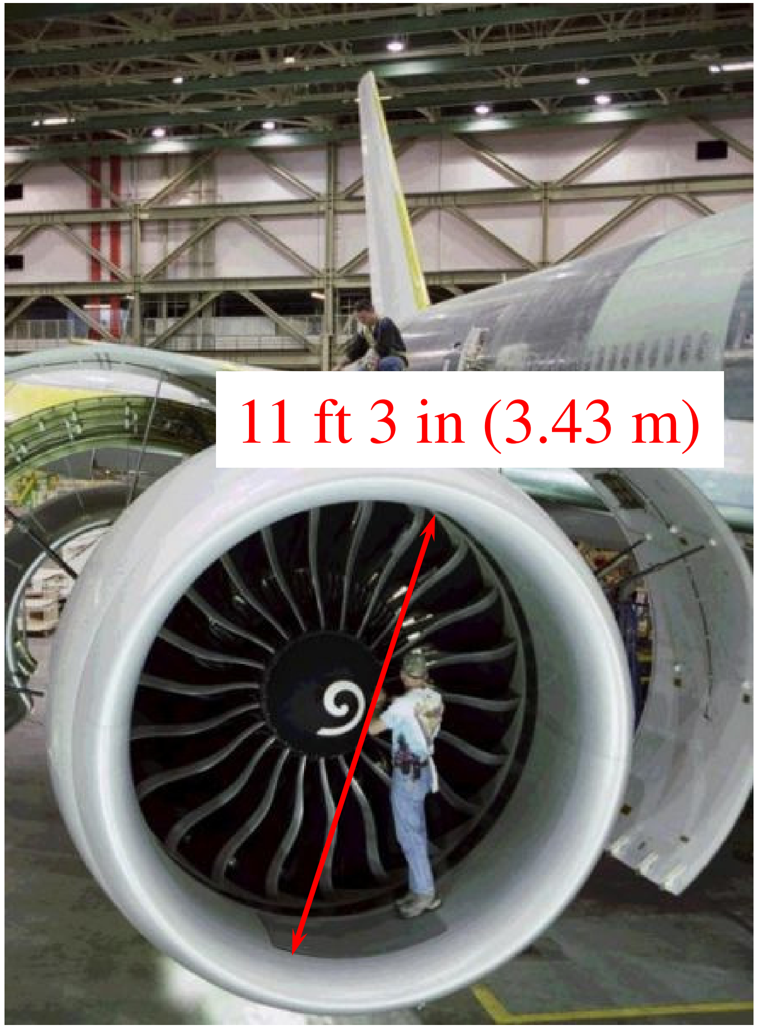


Similar to PWJT4A: T=17,000 lbf, $\alpha \sim 1$



General Electric GE 90-115B:
T=115,000 lbf , $\alpha \sim 7$

HOW LARGE IS THE 777-300 ENGINE?



GE90 115B is the largest and the most powerful turbofan built (3.43 m in diameter)
In this case, 737 cabin is a mere 3% wider than 777 engine

Technology requirements for future turbo fan engines

Fan:
- low pressure ratio
- variable fan area nozzle or variable fan pitch
- high stability
- low noise
- low weight

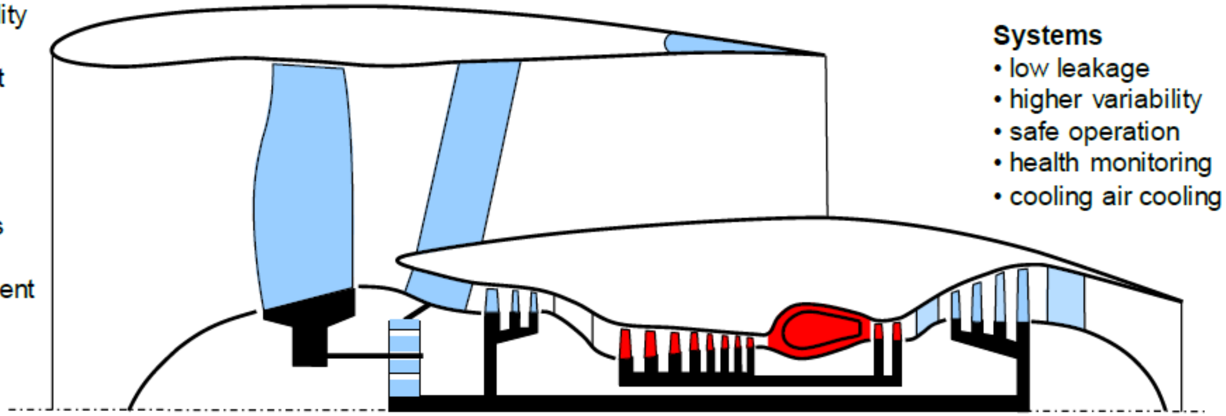
Nacelle:
- low drag
- low weight
- short air intake & nozzle
- noise abatement

Aircraft
Integration of engine & pylon

Structures
- low weight
- high stiffness

Systems
- low leakage
- higher variability
- safe operation
- health monitoring
- cooling air cooling

Gear box
- low losses
- heat management



LPC
- high speed
- high pressure ratio
- high stability
- low weight

HPC
- small size
- high efficiency
- high pressure ratio
- low weight

Combustor
- low emissions
- high pressure
- high inlet temp.
- operating range & stability

HPT
- high temperature
- reduced cooling
- high efficiency

LPT
- high speed
- high efficiency
- low weight
- reduced noise

Integrated design Duct-LPC-Duct-HPC

Integrated design HPT-TCF-LPT-TEC

Key yechnologies for fan

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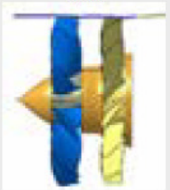
Low pressure ratio fan

Contra-rotating fan

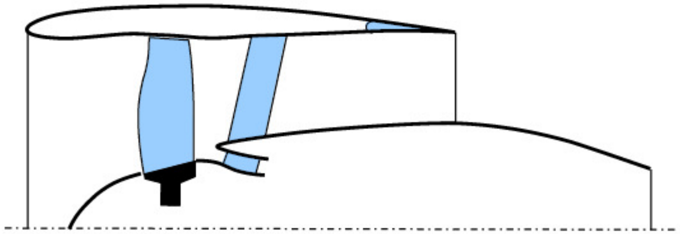


Lightweight fan

Lightweight intermediate case

Variable fan area nozzle

Power gearbox



Titanium Matrix Composite high torque shaft

Low noise fan design

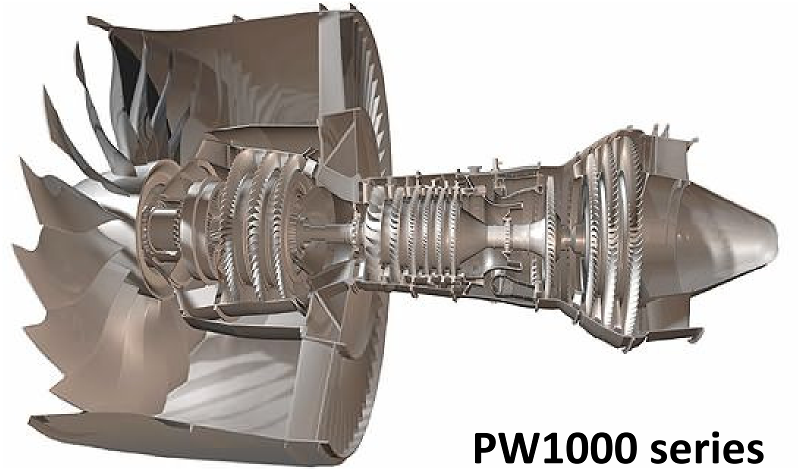
Acoustic liners

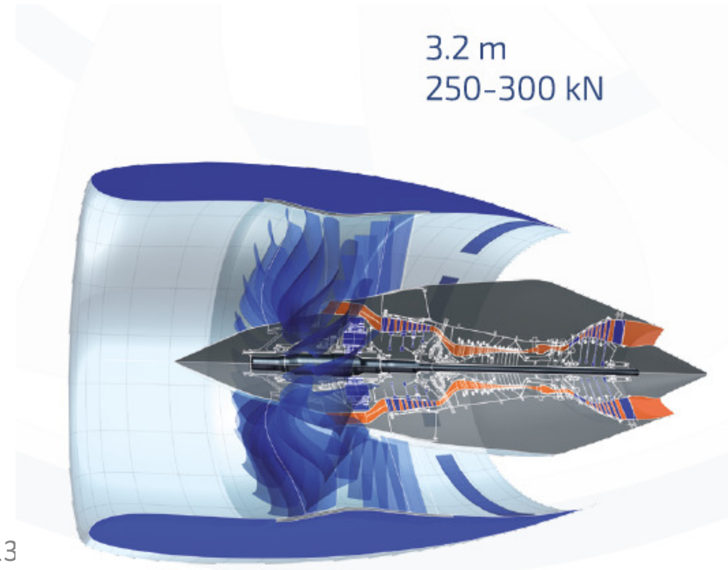
Lined outlet guide vanes

Active stator for noise reduction

Negatively scarfed inlet

Geared Turbofan





- Tip speed limit
- Increase by pass
- Increase diameter
- Reduction in fan tip speed increase in turbine speed
- Ultra high by-pass ratio with high opr

Key yechnologies compressors

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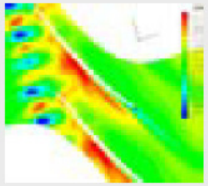
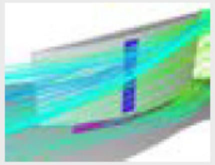
Surge control (tip injection)

Stall active control

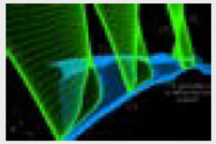
Casing treatment



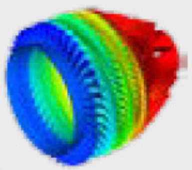
Aspirated blading



Non axi-symetric endwalls



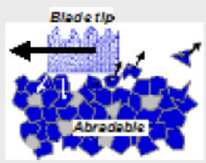
High speed booster



Lightweight high temperature outlet guide vane

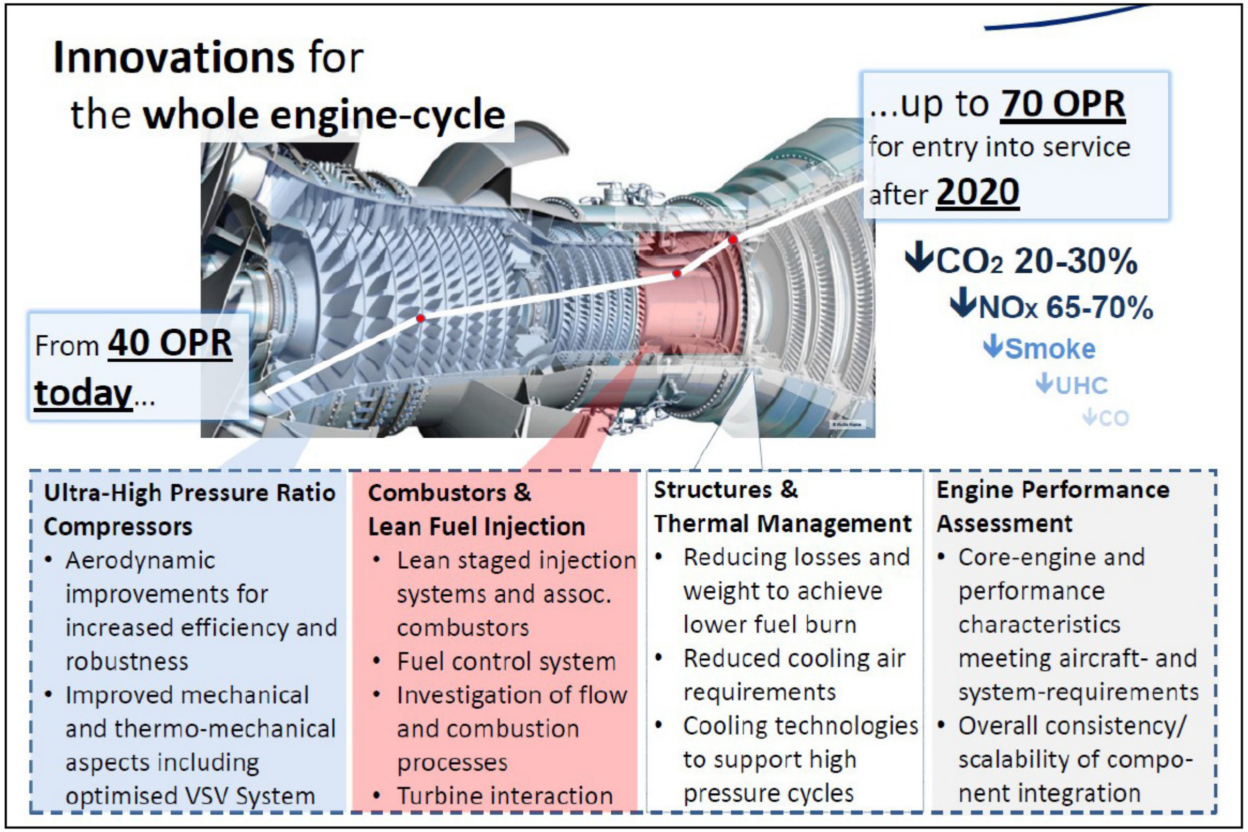
Advanced BLISK manufacturing & materials

Rub management



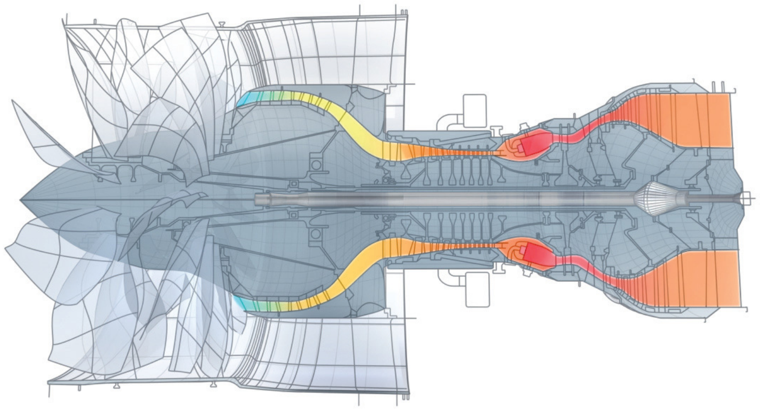
Active/passive clearance control

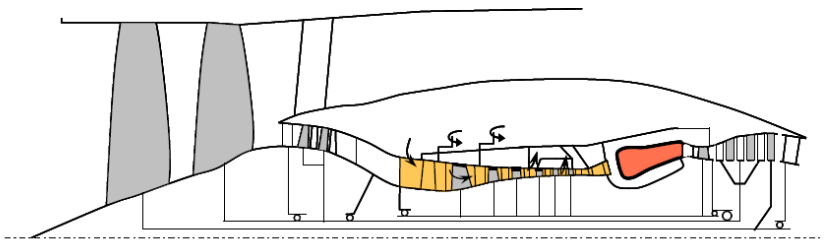
Increasing OPR



- Limit :size of last compressor stages
- Limit: tip clearance effect
- Intercooled compressor

Newac test vehicles: flow controlled core





Flow Controlled Core

Flow control technologies offer new opportunities to achieve an increase in high pressure compressor efficiency, additional surge margin and reduced in-service deterioration and can be applied to a contra rotating turbofan (CRTF). These technologies are:

- Tip flow control technologies including tip injection and aspiration
- Advanced 3D aerodynamics and air aspiration applied on stator, hub or blade
- Blade/casing rub management for tight tip clearance
- Flow stability control optimised for engine integration

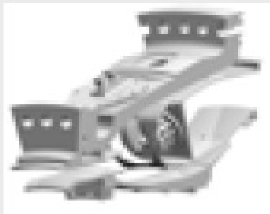
The flow control technologies will be investigated by analysis,

elementary tests and validated in a compressor rig test. For this application the Lean Direct Injection (LDI) combustor as well as the PERM combustor are well suited.

Key yechnologies combustors

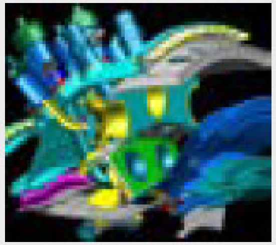
LPP combustor

PERM combustor

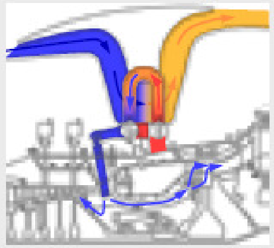


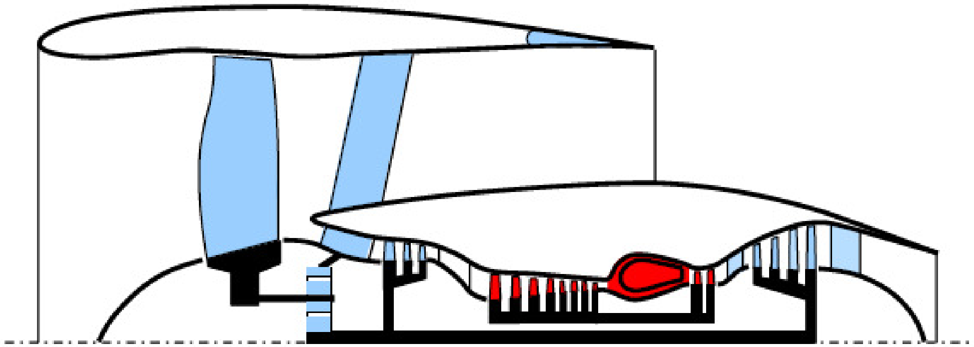
LDI combustor

Double annular combustor



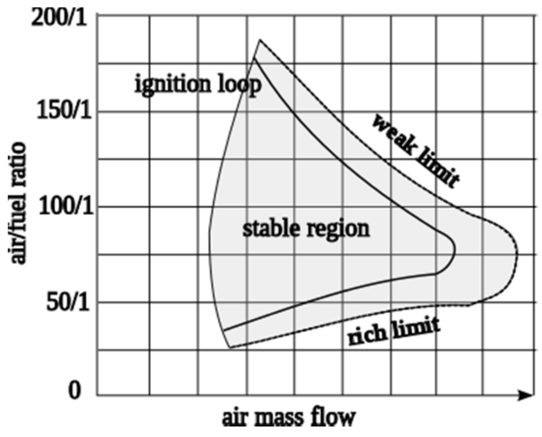
Active cooling air cooling



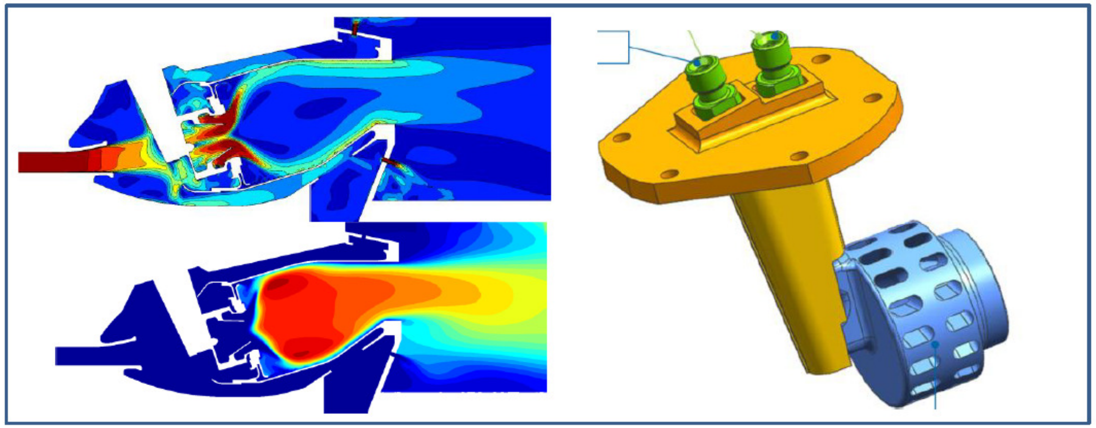


Increase TET

- Increasing Combustion temperature increase Nox creation
- Approaching stechiometric combustion increase unburned (rich limit)
- Require high level of cooling for turbine



Experimental test at GE Avio Aero

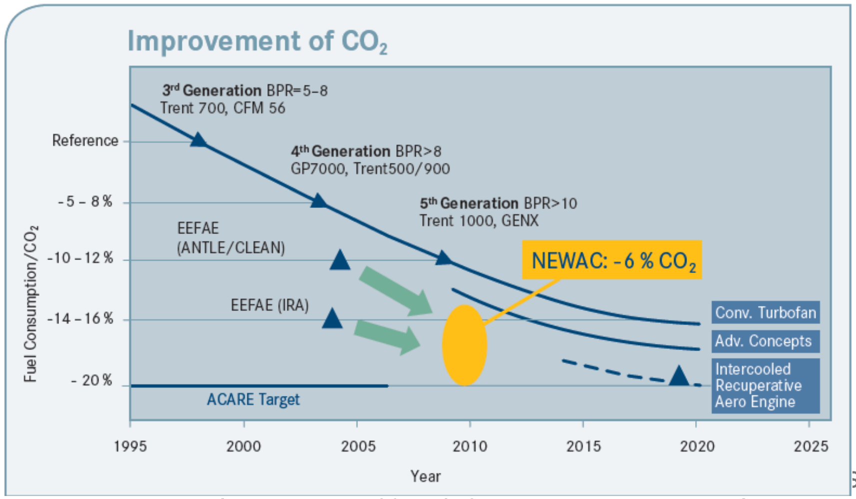


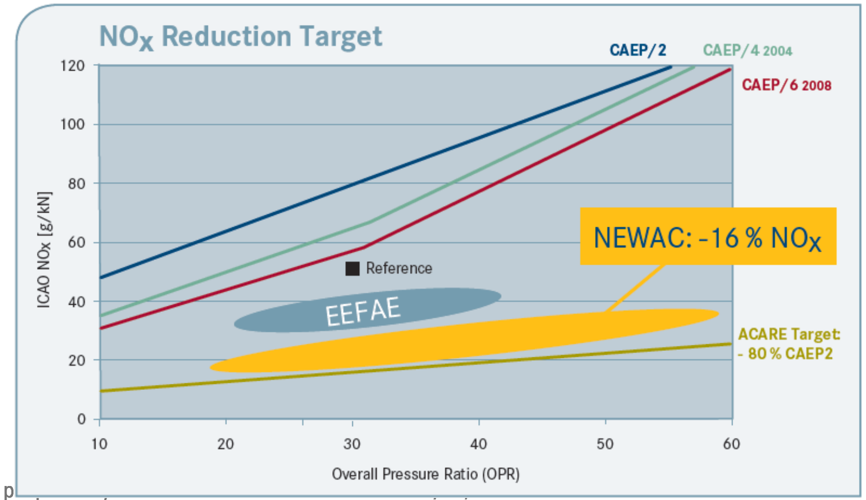
Mach number and temperature distribution in GE AVIO`s PERM combustor

PERM Development at GE AVIO (lhs: combustor assembly; rhs: instrumented liner)

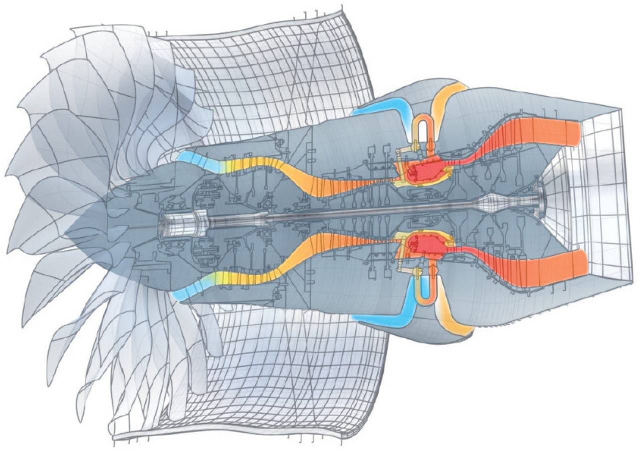
Decrease pollution

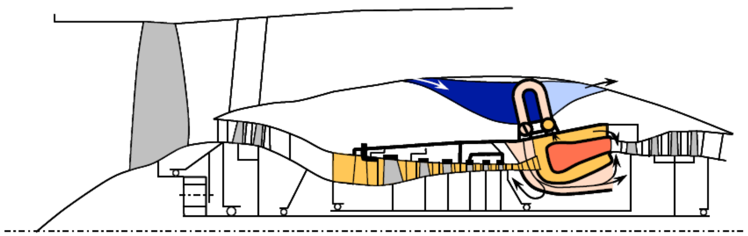
- Increase combustor extit temperature
- Stechiometric limit
- High NOx emission
- Unburned
- Improve combustion





Newac test vehicles: active core





Active Core

Active systems open up a new area of technological opportunities. They offer the possibility to adapt the core engine to each operating condition of the mission and, therefore, have the potential to optimise component and cycle behaviour. The most promising active systems for core engine applications will be investigated and compared with passive alternatives:

- Active cooling air cooling system for reduced cooling air consumption
- Active and semi-active clearance control system for the rear HPC stages
- Active surge control system for the front HPC stages

The candidates with the highest overall potential will be developed and validated in a final core test. A Partially Evaporating Rapid Mixing (PERM) combustor is best applicable to the active core engine.

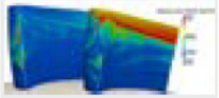
Key yechnologies turbine

High speed LPT

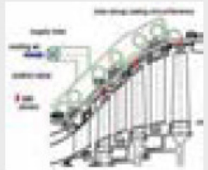
High lift airfoil & high stage loading

Low noise design

HPT for non-axisymmetric inflow (lean burn)



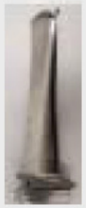
Active clearance control



Advanced cooling

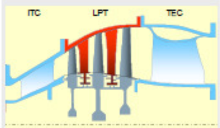
New coatings

TiAl blade

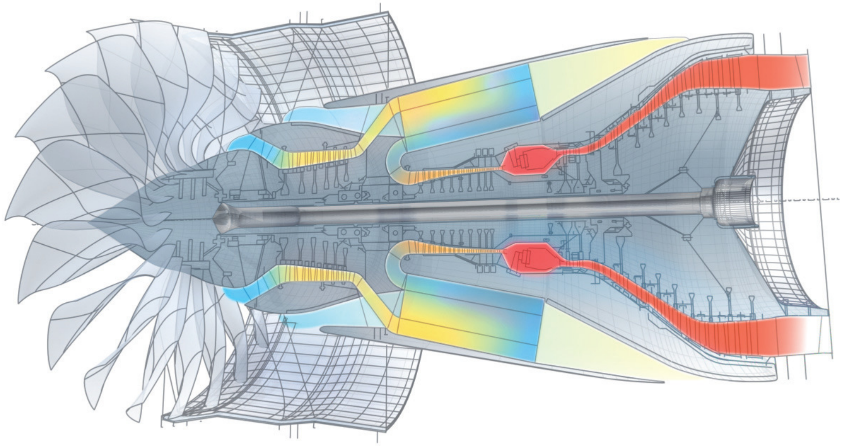


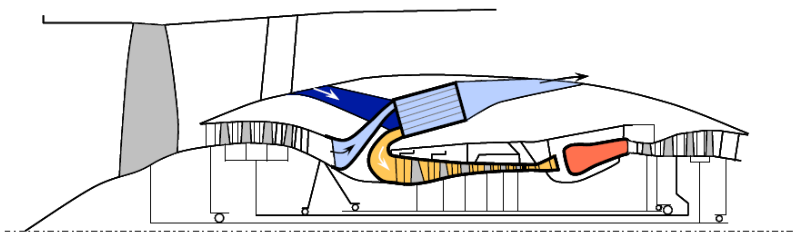
Turbine center frame

TCF-LPT-TEC interaction



Newac test vehicles: intercooled core





Intercooled Core

The application of intercooling to a core configuration allows for very high overall pressure ratios (OPR). By cooling the air between the two stages of compression it reduces the work input for such cycles and improves fuel burn. The lower combustor entry temperatures can also lead to reduced NOX. Key technologies of the intercooled core concept will be investigated in detail:

- An advanced compact and lightweight intercooler and its associated ducting
- A next generation highly efficient compressor which also meets the increased operability needs due to the added volumes in the system

These technologies will be validated by rig test. An advanced Lean

Direct Injection (LDI) combustor based on the EEFAE-ANTLE technology programme will be investigated as most appropriate for the high OPR of the intercooled core cycle.

Key yechnologies heat exchanger

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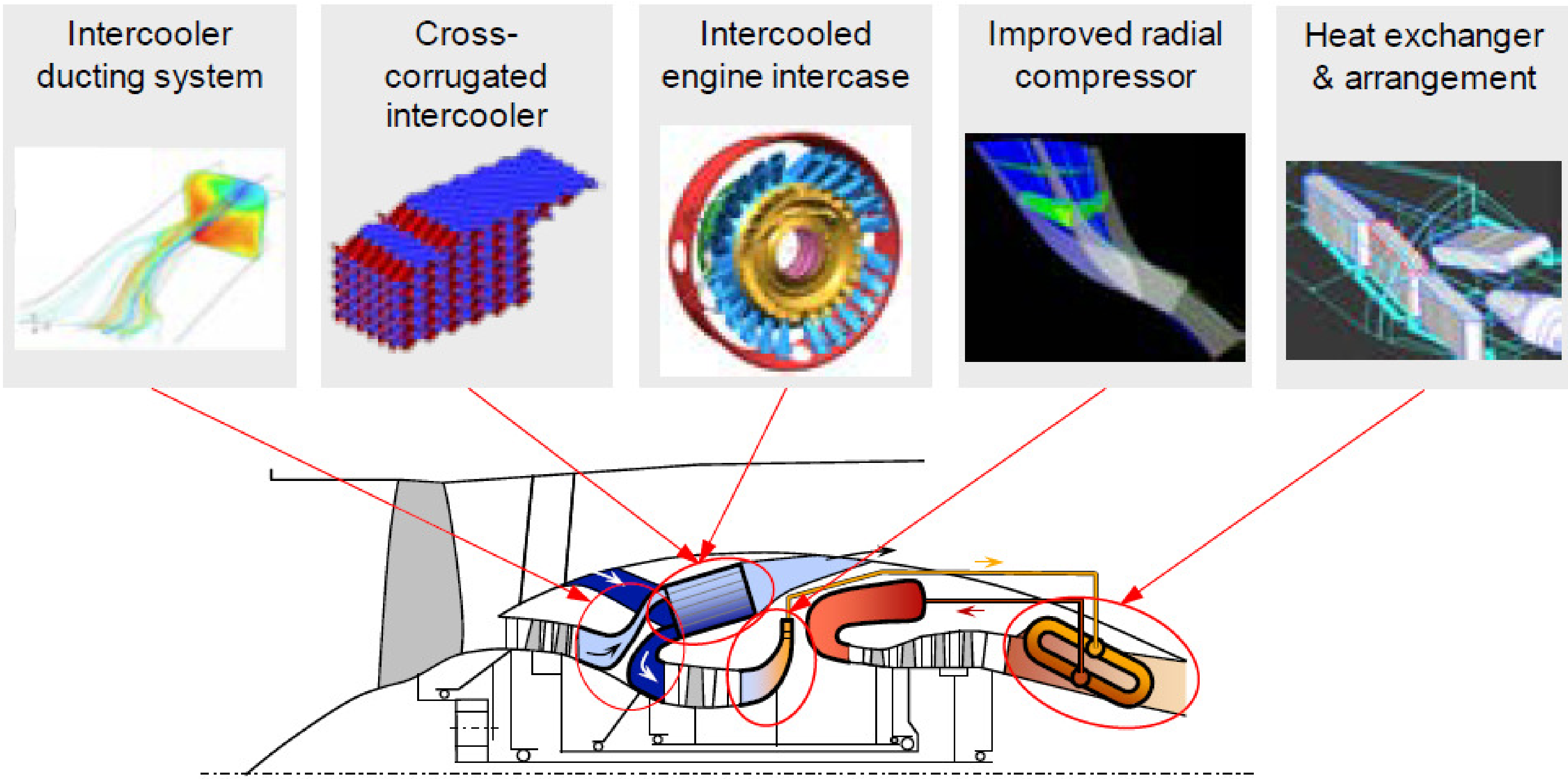
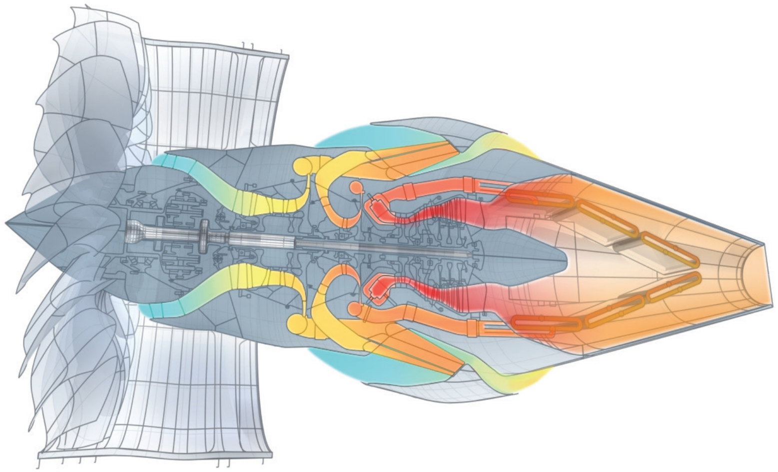
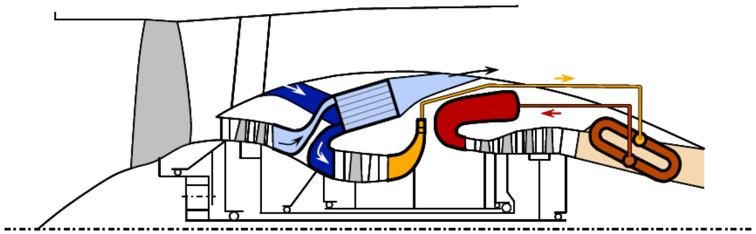


Newac test vehicles: intercooled recuperative core



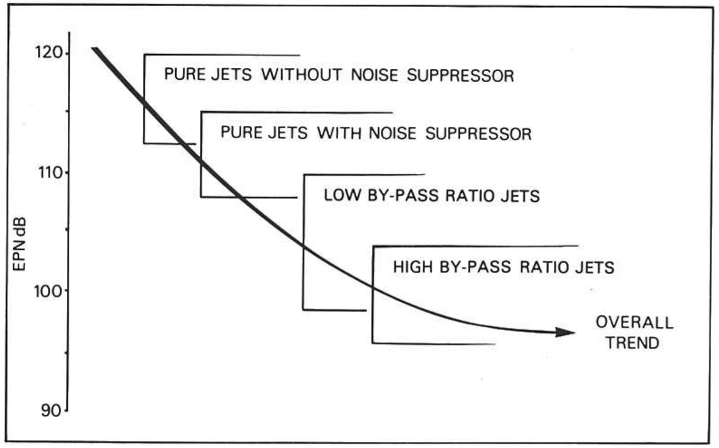


Intercooled Recuperative Core

This concept exploits the heat of the engine exhaust gas and maximises the heat pick-up capacity of the combustor inlet air by intercooling in front of the high pressure compressor. The results of the EEFAE-CLEAN technology programme showed improvement potential in the optimisation of the recuperator arrangement, by introducing an innovative duct design and by investigating a radial compressor in a new design regime. Finally, an advanced Lean Premixed Prevaporised (LPP) combustor, which is well suited for the intercooled recuperative cycle with its low overall pressure ratio, will support further NOX reduction.

AIRCRAFT AND ENGINE NOISE

- Increase in by-pass ratio decrease jet velocity decreaisng noise
- Better jet mixing decrease noise



Conclusions

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- Challenging targets
- Improved models and simulations
- Improved optimization process
- Increase cycle complexity
- Integration between engine and aircraft

The future?